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Noteworthy records of bats of the genus *Eumops* Miller, 1906 from Guatemala: first confirmed record of Underwood's Bonneted Bat, *Eumops underwoodi* Goodwin, 1940 (Mammalia, Chiroptera, Molossidae), in the country

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Abstract

Two species of *Eumops* Miller, 1906 are reported with voucher specimens from Guatemala: *E. auripendulus* (Shaw, 1800) and *E. ferox* (Gundlach, 1861). *Eumops underwoodi* Goodwin, 1940 has been known only by recordings. We collected dead specimens of *E. ferox* and *E. underwoodi* in a wind farm. Additionally, we provide acoustic data, and an allometric scaling hypothesis supports the identification of *E. underwoodi*, as it reflects the largest body size for sympatric free-tailed bats. We increase the list of bats in Guatemala to 104 species.

Keywords

Carcass, echolocation pulses, free-tailed bats, San Miguel Escobar, Villa Canales, wind turbines

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Introduction

Eumops Miller, 1906 is the most species-rich genus in the family Molossidae, comprising 17 high-flying aerial insectivorous bat species distributed from the southern United States to Patagonia in Argentina (Eger 1977; Medina et al. 2014; Simmons and Cirranello 2020). In Guatemala, the genus is underrepresented, probably due

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to high aerial flight and consequent difficulty to make captures with conventional techniques such as mist nets (Reid 2009); efforts to inventory bats throughout the country are also low. There are only two species of *Eumops* reported: *Eumops auripendulus* (Shaw, 1800) from southern Guatemala and *Eumops ferox* (Gundlach, 1861) from the northeastern part of the country (Trombone 2016; Kraker-Castañeda et al. 2016; Muñoz-Alonzo 2020). Previously, *E. ferox* was considered a subspecies in the *E. glaucinus* complex, now restricted to South America (McDonough et al. 2008; Baker et al. 2009; Pérez et al. 2012; Kraker-Castañeda et al. 2016). *Eumops underwoodi* Goodwin, 1940 was only known in Guatemala by recordings (Miller and Pérez 2004).

Wild Bonneted Bat, *Eumops ferox* (Gundlach, 1861), occurs in Cuba and Jamaica, Mexico, and Central America (McDonough et al. 2008; Baker et al. 2009). This species inhabits evergreen forests, deciduous forests, pine-oak forests, subtropical moist forests, and thorn scrubs at elevations below 1800 m (Pérez et al. 2012), with many reports coming from big cities and towns (Best et al. 1997; Reid 2009). In Guatemala, it was reported in a single locality in San Lorenzo Marmol, Río Hondo municipality, Zacapa department, in a pine-oak forest ecosystem (Pérez et al. 2012).

Underwood's Bonneted Bat, *Eumops underwoodi* Goodwin, 1940, is distributed from Arizona, USA, to Guanacaste, Costa Rica (Kiser 1995; Simmons 2005; Pineda et al. 2008; Reid 2009; Miller et al. 2016). This species inhabits dry forests, arid regions, semideciduous forests, and tropical forests at elevations below 1960 m (Hall 1981; Kiser 1995; MacSwiney et al. 2003; Iñiguez-Dávalos 2005; Reid 2009; Ceballos et al. 2013; Miller et al. 2016). In Central America, it is reported from a few scattered locations and is assumed to be present in Guatemala based on its wide distribution and indirect evidence, such as recordings (Eger 1977; Kiser 1995; Miller and Pérez 2004; Iñiguez-Dávalos 2005; Reid 2009; Miller 2016). Miller and Pérez (2004) reported *E. underwoodi* for the first time in a tropical forest in Mirador Río Azul National Park, San Andrés municipality, Petén department, through acoustic detection. However, this species was not included in the last checklist of bats of Guatemala (Kraker-Castañeda et al. 2016), because of the lack of voucher specimens.

Eumops species can be recorded with ultrasonic detectors and show characteristic search-phase echolocation pulses of long duration, low frequency, and narrow bandwidth (Miller 2003; Jung et al. 2014; Zamora-Gutiérrez et al. 2016), with some species vocalizing in the human audible spectrum (Mora and Torres 2008). Based on the phylogenetic convergence hypothesis, we expect species in the same genus to be acoustically similar, and due to allometric scaling, frequency-based parameters are expected to be inversely correlated to body size (Jung et al. 2014). *Eumops underwoodi* is the largest species of free-tailed bats distributed in the region, exhibiting the longest forearm (65–75 mm; Taylor et al. 2019). Therefore, it should emit low-frequency echolocation pulses, the lowest in this group of bats.

Here, we report carcasses of *E. ferox* and *E. underwoodi* found at Villa Canales municipality, Guatemala department, and we include recordings from the same locality and another relatively nearby locality in the central region of the country. The carcass of *E. underwoodi* represents the first direct evidence of this species in the country, and our new data contributes to filling distribution gaps in northern Central America.

Methods

We collected two dead specimens found on the ground under a wind farm's turbines at Los Llanos village, approximately 5.7 km south and 3.5 km west of Santa Elena Barillas, Villa Canales municipality, Guatemala department, Guatemala (Fig. 1). This village is on the northern slope of the Pacaya volcano, near the southern edge of the metropolitan area of Guatemala City. The vegetation in the area is premontane humid forests, with predominant pine-oak species associations. The wind farm's surrounding landscape is constituted mainly by native forests, grasslands, reforestation patches, corn, coffee, pineapple crops (mostly), meadows, urbanization, and industrial infrastructure (Ixcot et al. 2007; IARNA-URL 2018).

We photographed the carcasses and took the following measurements in the field: total length (TL), tail length (T), ear length (E), foot length (F), and forearm length (FA). The specimens were temporarily frozen and then transported to the Escuela de Biología of the Universidad de San Carlos de Guatemala (USAC), Guatemala City. In the laboratory, the carcass of *Eumops ferox* was prepared as a skin and skeleton. Because of the skull damage we only include the following cranial measurements: zygomatic width (ZW), width across upper canines (CC), maximum external width between left and right upper molars (WUM), length of maxillary toothrow (CM3), and length of mandibular toothrow (CM_3). The carcass of *Eumops underwoodi* was unfortunately lost during a collection transfer process. However, we archived photographs in the Photographic Mammal Collection of USAC (USACF).

We made the recordings using Anabat (Titley Scientific Electronics) in the same locality where we found the carcasses and also approximately 30 km away in Finca Bella Vista, San Miguel Escobar municipality, Sacatepéquez department. The Anabat has a highly directional condenser microphone, which results in a longer than wider detection field (Larson and Hayes 2000). In Los Llanos, we used an Anabat SD1, and in Finca Bella Vista we used an Anabat II connected to a laptop with the ZCAIM (Zero-crossing Analysis Interphase Module; Kraker and Pérez 2012). The Finca Bella Vista coffee plantation (Fig. 1) is outside the city of Antigua Guatemala. Similar farms and urban development surround it. Here, coffee plants are grown in the shade of *Grevillea robusta* A. Cunn. ex R. Br. trees (Proteaceae). Around

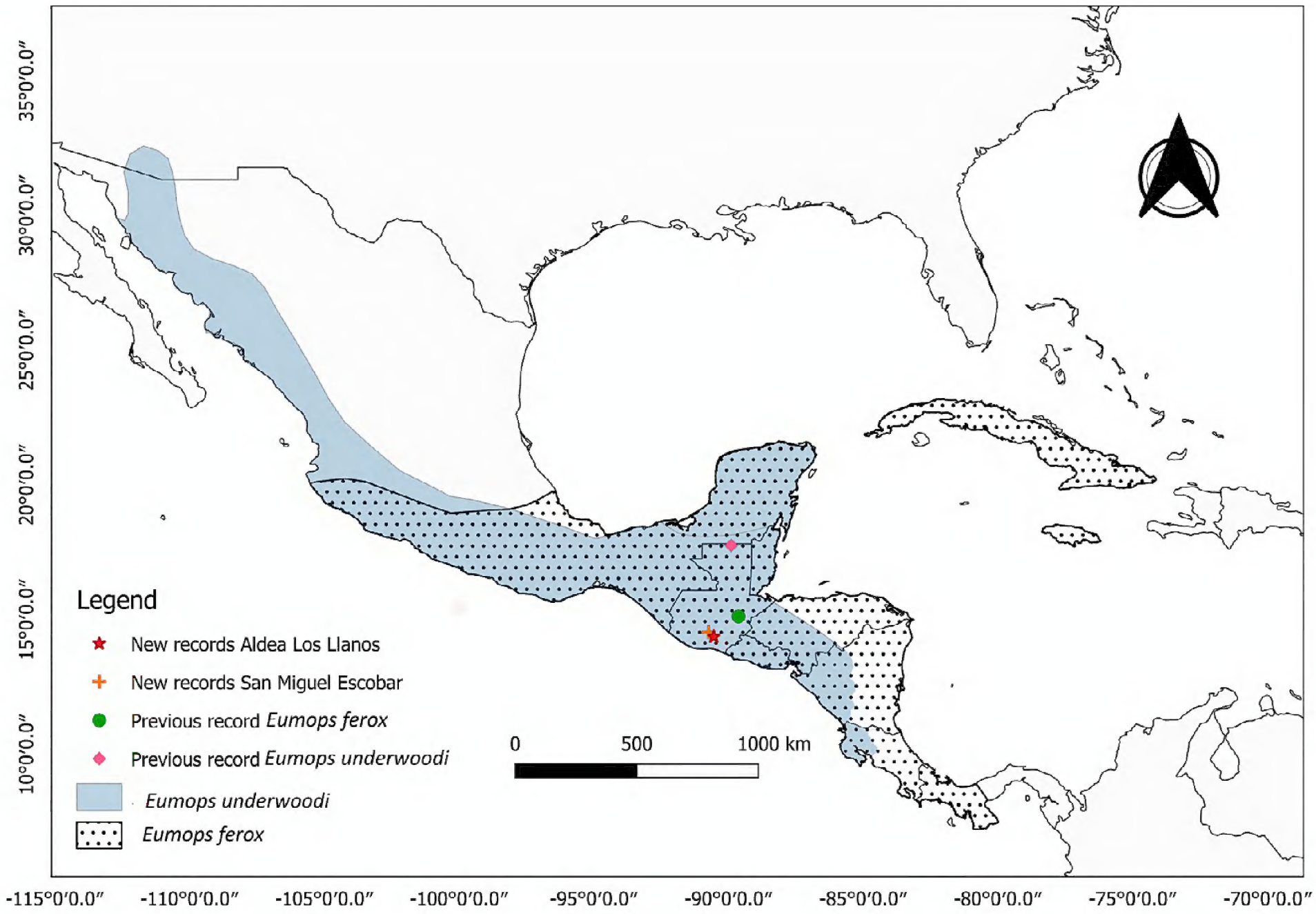

Figure 1. Distribution polygons for *Eumops underwoodi* and *E. ferox*, based on Taylor et al. (2019) and Solari (2019), respectively. We indicate the new collection localities in central Guatemala and the previous records in northern Guatemala.

June, the shade trees are pruned for better penetration and distribution of sunlight to the coffee plants below, leaving the area relative open. The detector's microphone was directed to the open area over the coffee plants.

As a first step, we processed the recordings in Kaleidoscope Pro v. 5.4.0 (Wildlife Acoustics, Inc.). This procedure allowed us a more efficient work given the high volume of recordings and the inconvenience of inspecting single files. We configured automatic classification for bats of the Neotropics in the Bat Analysis Mode, with a sensitivity +1 (more accurate). This way, we were able to select recordings of species of interest for depuration, specifically belonging to the genus *Eumops*. It is important to make corroborations because automatic classification may produce false positives (see Kaleidoscope Pro Help Topics; Rydell et al. 2017).

Finally, we proceeded with a manual characterization through qualitative and quantitative approaches, and measured the following acoustic parameters: 1) duration of the pulse (Dur, milliseconds or ms), 2) maximum frequency of the pulse (F_{max}, kHz), 3) minimum frequency of the pulse (F_{min}, kHz), 4) bandwidth (F_{max}–F_{min}, kHz), and 5) characteristic frequency of the pulse (F_c, kHz), which is measured taking as reference the point of change of slope (knee) where the body begins (the flattest portion of the pulse) until the end of the body, at this point (Gannon et al. 2004). For this purpose, we used AnalookW v. 4.1t (C. Corben 2015).

Results

We report *Eumops ferox* and *Eumops underwoodi* in central Guatemala based on dead specimens collected from Los Llanos. Our identification was based on external and cranial measurements (Table 1). Also, we include recordings from Los Llanos (possibly *E. ferox* or *Nyctinomops macrotis*; Supplementary Data 1) and Finca Bella Vista (*E. underwoodi*; Supplementary Data 2). These localities separated by approximately 30 km (Fig. 1). Of 2868 audio files and based on visual inspection of the recordings identified as *Eumops* species, we obtained three matches of a sonotype that could belong to *E. ferox*, representing three sequences and 10 pulses (Table 2). However, we also suggest an alternate identification: *Nyctinomops macrotis* (previously collected in the same locality; Trujillo et al. 2020). Other bats with similar echolocation pulses' structure are *N. laticaudatus* (É. Geoffroy, 1805) and *Tadarida brasiliensis* (I. Geoffroy, 1824) (Miller 2003). However, the latter are of smaller body size (see Taylor et al. 2019), and hence should produce higher frequencies. *Nyctinomops laticaudatus* has been collected in Los Llanos and *T. brasiliensis* occurs potentially in the area. We also obtained three matches of *E. underwoodi*, representing three sequences and 14 echolocation pulses (Table 3).

Table 1. Comparison of diagnostic morphometric characters used to identify *Eumops underwoodi*, *E. ferox* and *Nyctinomops macrotis*. The values were obtained from specimens found dead in a wind farm at Los Llanos, Villa Canales, Guatemala. All measurements are given in millimeters (mm).

	Nyctinomops macrotis (*n* = 1) USAC 06041 Trujillo et al. 2020	*Eumops ferox* (*n* = 1) USAC 06198 This study	*Eumops underwoodi* (*n* = 1) This study
Sex	♀	♂	♂
FA	61	61	75
TL	134	133	147
T	54	47	50
F	14	13	na
E	30	22	24
GSL	23.6	na	na
HB	7.97	na	na
MB	12.45	na	na
ZB	na	14.46	na
PO	4.35	na	na
LR	6.3	na	na
CC	5.01	5.72	na
WUM	8.94	10.35	na
CM3	8.96	9.28	na
PL	8.51	na	na
LM	17.31	na	na
CM3	9.98	10.48	na

Table 2. Acoustic parameters measurements of a sonotype belonging to the family Molossidae, possibly *Eumops ferox* or *Nyctinomops macrotis*, which are of similar body size, from recordings of this study in central Guatemala. For each acoustic parameter (see details in the Methods section), we calculated the mean, followed by the standard deviation (SD), the coefficient of variation (CV), the minimum and maximum values, and the range (the difference between maximum and minimum).

Sequence	Pulse	Dur	F_{max}	F_{min}	F_{max}–F_{min}	F_c
1	1	6.1	23.6	19.3	4.3	20.5
1	2	5.4	23.6	19.1	4.5	19.4
1	3	6.1	22.9	18.6	4.3	19.8
2	4	6.0	22.3	20.6	1.7	20.6
2	5	8.3	22.1	20.1	2.0	20.5
2	6	9.4	22.3	19.8	2.5	20.0
3	7	9.3	21.2	18.6	2.6	18.6
3	8	10.4	20.8	18.3	2.5	19.3
3	9	10.5	21.5	19.8	1.7	20.3
3	10	10.5	22.2	19.8	2.4	19.9
	Mean	8.2	22.3	19.4	2.9	19.9
	SD	2.0	0.9	0.7	1.0	0.6
	CV	24.3	4.0	3.6	36.5	3.1
	Minimum	5.4	20.8	18.3	1.7	18.6
	Maximum	10.5	23.6	20.6	4.5	20.6
	Range	5.1	2.8	2.3	2.8	2.0

Eumops ferox Gundlach, 1861

Material examined. GUATEMALA – **Guatemala** • Villa Canales municipality, Los Llanos village; 14°36′25″N, 090°55′27″W; 1240 m a.s.l.; 04/XI/2015; R. Barahona leg.; 1♀; USAC 06198. • Villa Canales Municipality, Los Llanos village; 14°36′25″N, 090°55′27″W; 1240 m a.s.l; 04/I/2013, 07/I/2013, 12/III/2014; A. Medina-Fitoria leg. (acoustic records).

Identification. The identification of *E. ferox* was based on external and cranial measurements that match with those described by Best et al. (1997), Baker et al. (2009), Reid (2009), and Taylor et al. (2019), as diagnostic for the species (Table 1). *Eumops ferox* is smaller than *E. underwoodi* but similar in size to *E. auripendulus*, and it can be distinguished in the field in having the base of the hair white and the tragus square and broad. Additionally, *E. ferox* can be distinguished from *E. auripendulus* by having a poorly developed sagittal crest and a palatal foramen present (Fig. 2A, B).

Eumops underwoodi Goodwin, 1940

Material examined. GUATEMALA – **Guatemala** • Villa Canales municipality, Los Llanos village; 14°36′25″N, 090°55′27″W; 1240 m a.s.l.; 26/VIII/2015; R. Barahona leg. (photographic record); 1♀; USACF000004.1 to USACF000004.5 • Villa Canales municipality, Los Llanos village; 14°36′25″N, 090°55′27″W; 1240 m a.s.l; 05/I/2013, 07/I/2013, 12/III/2014; A. Medina-Fitoria leg. (acoustic records) – **Sacatepéquez** • San Miguel Escobar municipality, Finca Bella Vista; 14°52′92.3″N, 90° 74′67.3″W; 1530 m a.s.l; 17/XII/2008; C. Kraker leg. (acoustic records).

Identification. The identification of *E. underwoodi* was based on external diagnostic measurements that match with those described by Kiser (1995), Iñiguez-Dávalos (2005), Reid (2009), and Taylor et al. (2019) (Table 1). The specimen is comparatively large, with moderately large and heavily keeled ears, a small and rounded tragus, a large and low antitragus, and grayish-brown fur with paler venter (Fig. 3A). We also recognized *E. underwoodi* by the presence of bristle-like rump hairs on its low dorsum (Fig. 3B).

The echolocation pulses are of comparatively low frequency, long duration, and narrow bandwidth, characteristic of this genus (Jung et al. 2014; Zamora-Gutierrez et al. 2016). They possibly represent commuting pulses (B. Miller pers. comm). The diagnostic acoustic parameters of F_{min} ranged from 10.5 to 13.3 kHz and F_c from 10.9 to 13.8 kHz (Table 3). These measurements match those of other publications that present zero-crossing recordings of *E. underwoodi*; specifically, the minimum frequency (Table 3; García-Luis and Briones-Salas 2017). We also considered the allometric scaling hypothesis to support the acoustic identification of *E. underwoodi*, specifically because the echolocation pulses reflect the largest body size for free-tailed bats in the region, which is supported by previous collections in the locality (Trujillo et al. 2020). We contrasted our identification with a sonotype, possibly *E. ferox* or *N. macrotis*, which are of similar body size but smaller than *E. underwoodi* (Figs. 4A, B, 5).

Discussion

Several authors have considered Guatemala as part of the distribution of *E. underwoodi* (Eger 1977; Kiser 1995;

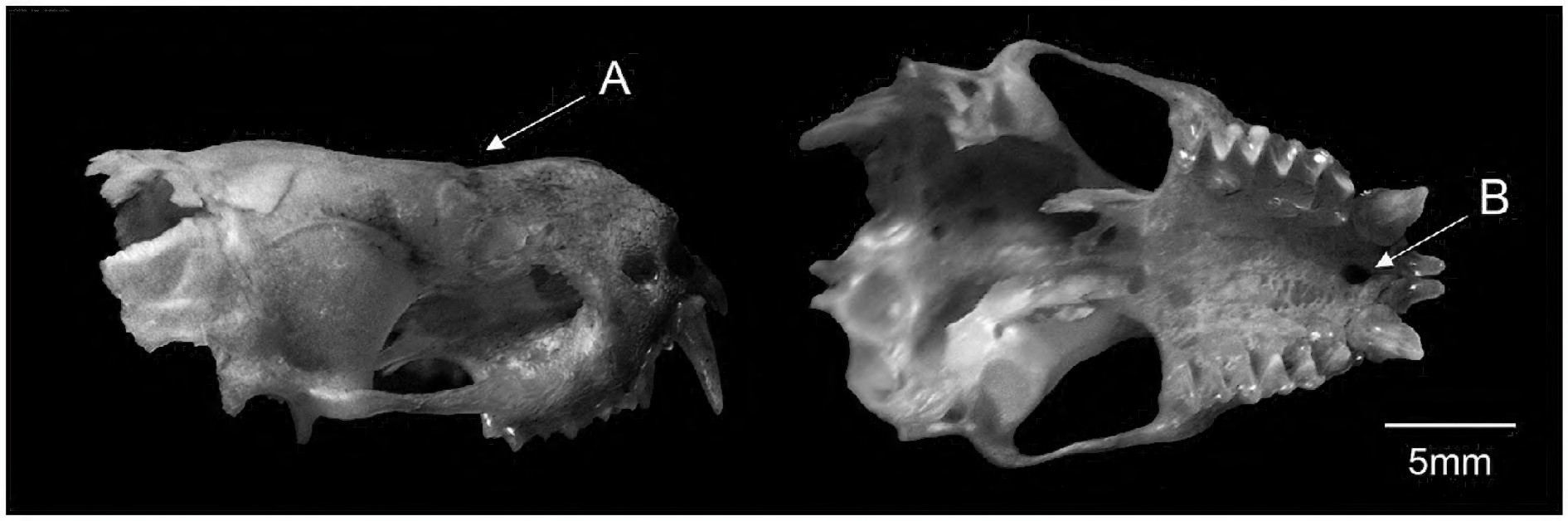

Figure 2. Lateral and ventral view of the skull of *Eumops ferox* (USAC 06198) from Los Llanos, Villa Canales, Guatemala. **A.** Poorly developed sagittal crest. **B.** Palatal foramen.

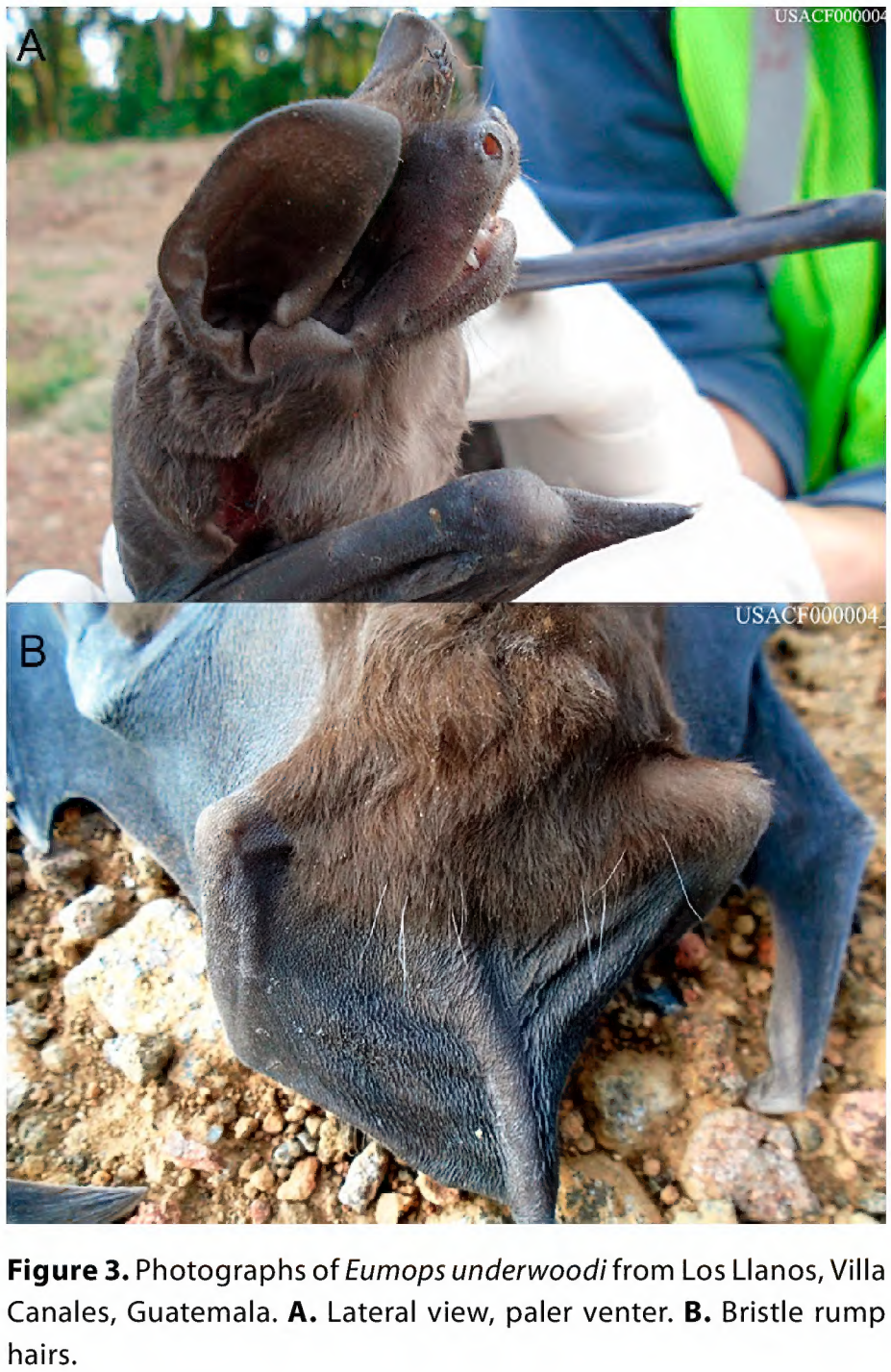

Figure 3. Photographs of *Eumops underwoodi* from Los Llanos, Villa Canales, Guatemala. **A.** Lateral view, paler venter. **B.** Bristle rump hairs.

Iñiguez-Dávalos 2005; Reid 2009; Miller 2016, Taylor et al. 2019). Our observations, specifically the finding of carcasses, confirm of the presence of this species in the country. We provide evidence that this species inhabits other ecosystems (premontane humid forests) and agro-ecosystems (coffee and pineapple crops). Most of the records come from dry, desertic ecosystems and semideciduous forests across the Pacific coast of the USA and Mexico, with only a few records from subtropical and tropical forests in the Yucatán Peninsula in Mexico and Central America (Kiser 1995; MacSwiney et al. 2003; Iñiguez-Dávalos 2005; Reid 2009; Miller et al. 2016).

Table 3. Acoustic parameters measurements of *Eumops underwoodi*, from recordings of Kraker and Pérez (2012)* and this study** in central Guatemala. For each acoustic parameter (see details in the Methods section), we calculated the mean, followed by the standard deviation (SD), the coefficient of variation (CV), the minimum and maximum values, and the range (the difference between maximum and minimum). In the last row, we include reported values ($\bar{x} \pm$ SD) for *E. underwoodi* in Oaxaca, Mexico, retrieved from García-Luis and Briones-Salas (2017), obtained from zero-crossing recordings.

Sequence	Pulse	Dur	F_{max}	F_{min}	F_{max}–F_{min}	F_c
1*	1	13.2	14.2	12.9	1.3	12.9
1	2	10.5	14.4	13.3	1.1	13.8
1	3	15.4	15.2	13.2	2.0	13.5
1	4	15.0	14.1	12.9	1.2	12.9
1	5	7.8	13.7	12.9	0.8	12.9
1	6	10.3	13.9	12.7	1.2	12.9
2*	7	11.9	13.0	11.5	1.5	11.5
2	8	10.7	12.8	11.3	1.5	11.3
2	9	9.3	12.9	11.5	1.4	11.5
2	10	14.5	12.7	10.9	1.8	10.9
2	11	15.9	12.7	10.9	1.8	10.9
3**	12	14.5	13.4	11.4	2.0	11.9
3	13	9.4	14.3	12.6	1.7	13.0
3	14	11.1	13.8	10.5	3.3	12.7
Mean		12.1	13.7	12.0	1.6	12.3
SD		2.5	0.7	0.9	0.6	0.9
CV		20.8	5.4	7.8	35.7	7.5
Minimum		7.8	12.7	10.5	0.8	10.9
Maximum		15.9	15.2	13.3	3.3	13.8
Range		8.1	2.5	2.8	2.5	2.9
García-Luis and Briones-Salas (2017)		9.7 ± 1.7	15.4 ± 1.6	11.9 ± 0.5	ND	ND

Complementarily, we provide the second report of *E. ferox* in the country, which was previously known from northeastern Guatemala (Pérez et al. 2012).

We argue that the identity of *E. underwoodi* is supported by the recordings using the allometric scaling hypothesis, producing very low frequencies in the human audible spectrum. Moreover, the measurements of the acoustic parameters match those reported in the literature (Table 3; García-Luis and Briones-Salas 2017). Based on the structure of the pulses, we believe that the

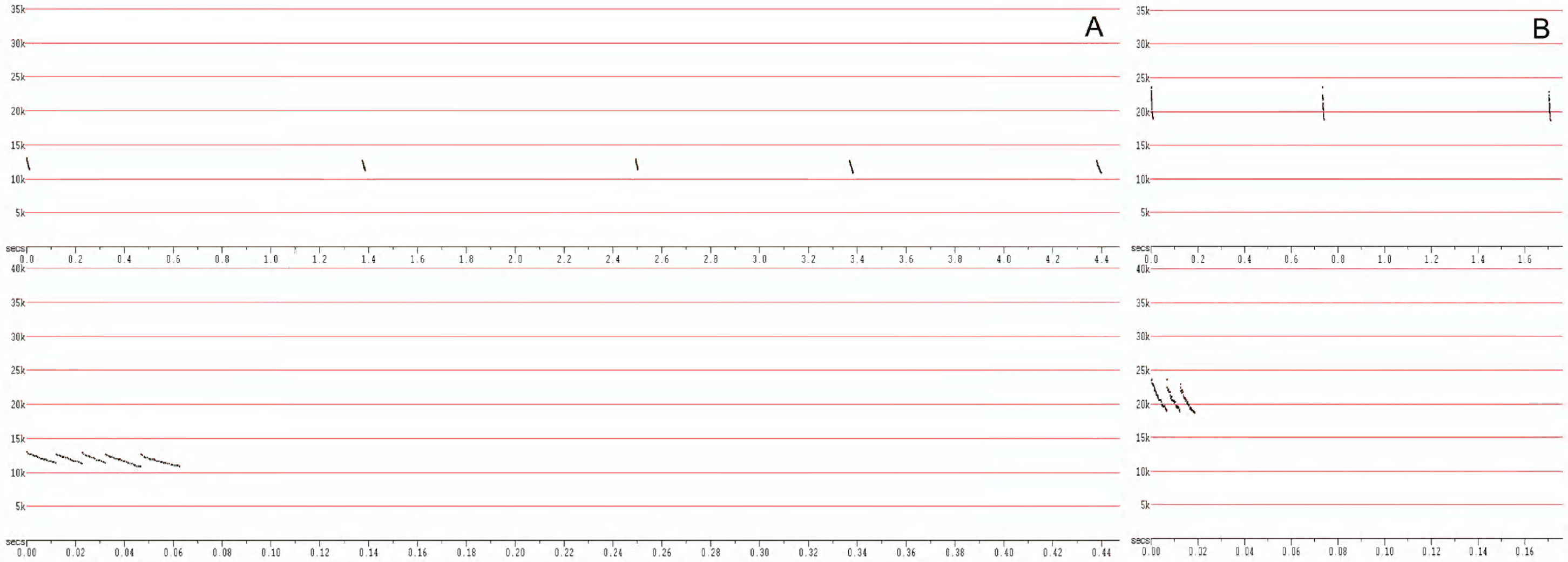

Figure 4. Spectrograms showing sequences of echolocation pulses. **A.** *Eumops underwoodi*, which is the largest-bodied molossid species (FA 65–75 mm; Taylor et al. 2019). **B.** Sonotype, possibly *E. ferox* or *Nyctinomops macrotis*, which are molossids of similar body size (FA 55–63 mm and 54–65, respectively; Taylor et al. 2019). On top, we display the echolocation pulses in true-time, and on bottom, we display the echolocation pulses compressed.

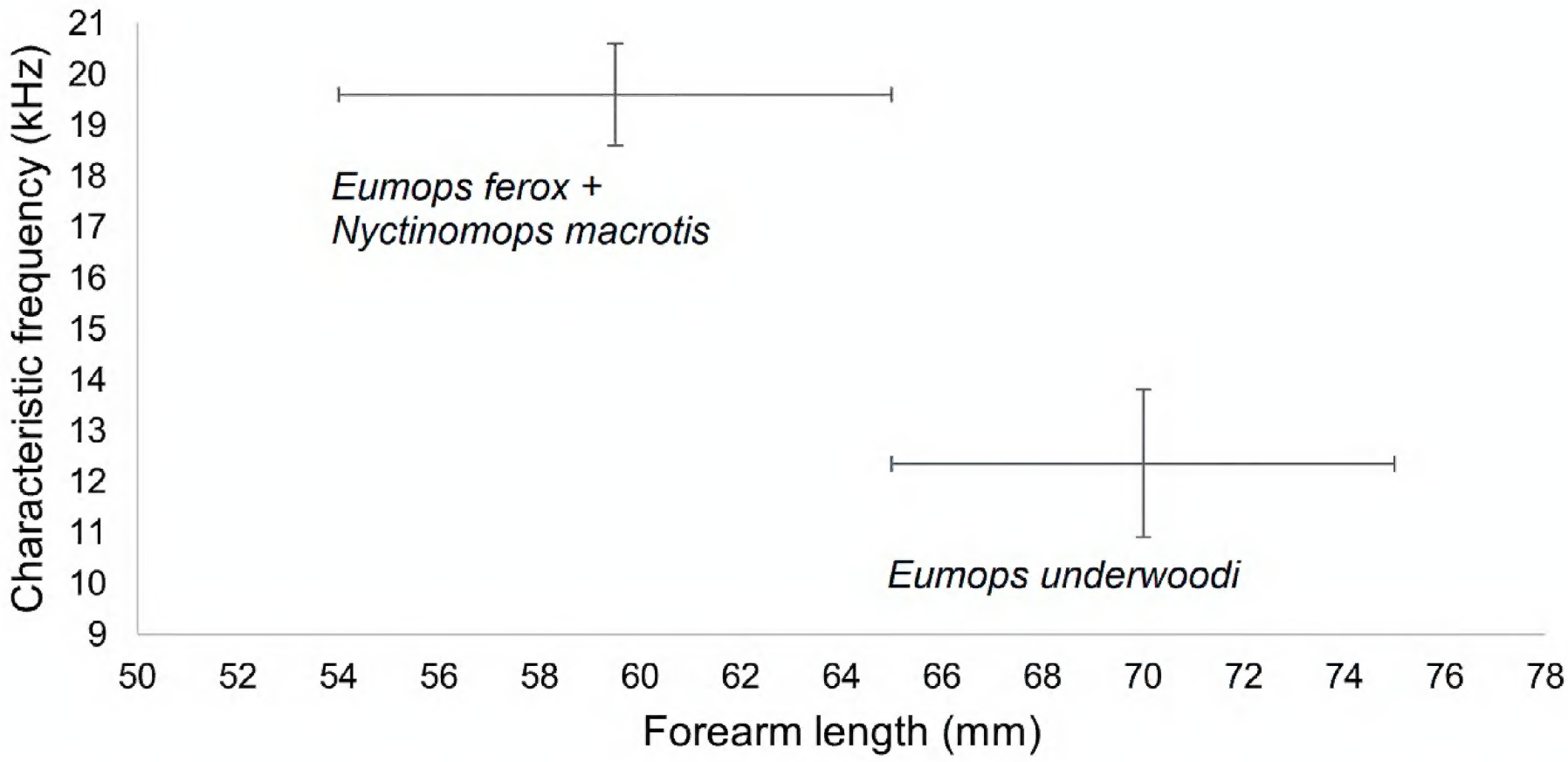

Figure 5. Forearm length (mm) and characteristic frequency (kHz) of *Eumops ferox* and *Nyctinomops macrotis* (FA 55–63 and 54–65 mm, respectively; Taylor et al. 2019), which we consider together as a sonotype, and *E. underwoodi* (FA 65–75 mm; Taylor et al. 2019). The horizontal and vertical whiskers represent the minimum and maximum values.

only potentially confusing species could be *E. ferox* or *N. macrotis* (Miller 2003). However, *E. ferox* and *N. macrotis* are smaller species (Table 1). Jung et al. (2014) developed an allometric scaling analysis of free-tailed bats and found out that, even when the rule did not apply for some species in the genus *Eumop*s (*E. auripendulus* Shaw, 1800 vs. *E. glaucinus* Wagner, 1843), *Eumops dabbenei* Thomas, 1914, the largest member analyzed, showed the echolocation pulses with the lowest peak frequency.

Eumops is one of the most underrepresented group of bats in Guatemala, with only three previous collections, two of *E. auripendulus* and one of *E. ferox* (Pérez et al. 2012; Trombone 2016; Muñoz-Alonzo 2020). We increase the number of *Eumops* species in the country to three and, consequently, the number of molossid species 13 (Kraker-Castañeda et al. 2016; Trujillo et al. 2020). The *E. underwoodi* carcass represents this first conclusive report of this species in Guatemala, increasing the country's bat list to 104 species (Kraker-Castañeda et al. 2016; Trujillo et al. 2020).

Remarkably, the last four species added to the Guatemalan list of bats belong to the family Molossidae. Before this note, Trujillo et al. (2020) included three species of the genus *Nyctinomops*: *N. femorosaccus* (Merriam, 1889), *N. aurispinosus* (Peale, 1848), and *N. macrotis*. These records highlight the necessity to increase our knowledge about free-tailed bats and prioritize research efforts, mainly because the last new species reports were carcasses found in wind farms. These findings point out the negative impacts that developing wind energy projects might have on bat populations, and the importance of bat inventories with complementary techniques. We believe that the growing development of acoustic research in the country will provide valuable information about free-tailed bats and other taxonomic families, such as new localities, critical habitats, and insights on the ecology of many species.

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Author's Contributions

Conceptualization: LAT, CKC, RBF. Project administration: RBF, AMF, LAT. Writing – original draft: LAT, RBF, SGP, AMF, JH. Writing – review and editing: CKC, LAT. Data curation: LAT, CKC.

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Supplementary Data

Supplementary Data 1. Zero-crossing recording of a sonotype possibly belonging to *Eumops ferox* or *Nyctinomops macrotis* from Los Llanos, Villa Canales, Guatemala.

Supplementary Data 2. Zero-crossing recording of *Eumops underwoodi* from finca Bella Vista, San Miguel Escobar, Sacatepéquez, Guatemala.